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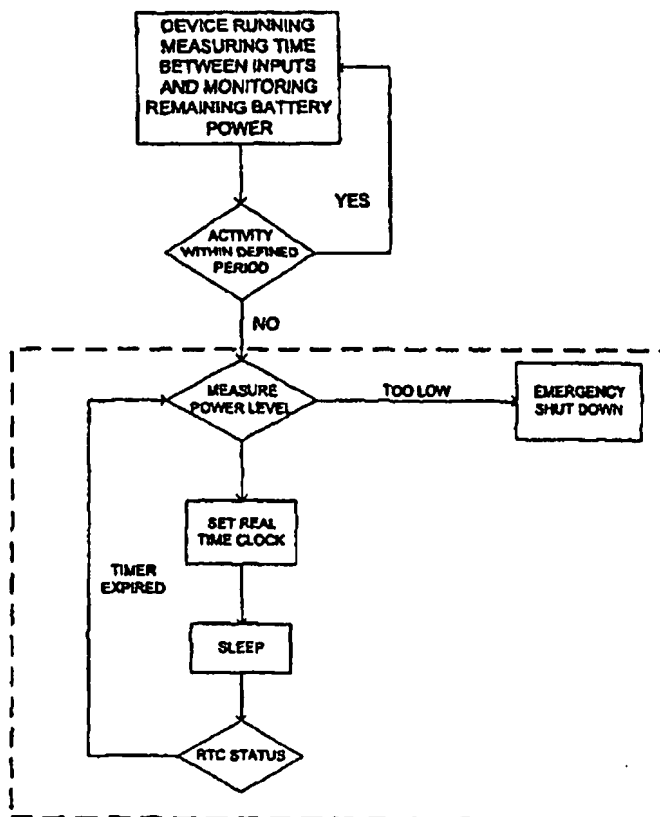**(19) World Intellectual Property Organization**
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(54) Title: POWER MANAGEMENT METHOD FOR USE IN ELECTRONIC DEVICES

(57) Abstract: A combination portable computer and mobile telephone device sends the portable computer portion into a sleep mode during periods of non-use; it can periodically and temporarily wake itself up so as to monitor the power consumption of a slave device, the mobile telephone, which depends on the same battery or power source.

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POWER MANAGEMENT METHOD FOR USE IN ELECTRONIC DEVICES

BACKGROUND OF THE INVENTION

5   1.   Field of the invention

This invention relates to a power management method for use in electronic devices. It is particularly applicable to combination devices powered by batteries comprising one portion which acts as a master and another portion which acts as a slave. Devices combining handheld computers (such as personal digital assistants) together with cellular

10   telephones, pagers and other portable radio devices are examples of such combination devices.

2   Description of the prior art

Power management for handheld devices such as personal digital assistants (PDAs),

15   cellular telephones and handheld computers present distinct problems to be resolved. Two problems in particular must be addressed: battery life and the protection of data stored in the device. Battery life is addressed by a number of different methods of reducing a device's power consumption, including causing the device to shut down (i.e. enter a low power consumption state) when not in use, referred to as going into a 'sleep'

20   mode, and by causing devices such as cellular telephones to camp, i.e., cycle on and off many times a minute, switching on only very briefly to determine if a call or message is being transmitted to the cellular telephone.

Certain types of electronic data storage, for example random access memories or RAM,

25   typically require that the device retain some electrical charge in its batteries to preserve stored data – if the battery is completely discharged, the data will be lost. To avoid loss of data, it is therefore common for such electronic devices to shut down completely before a certain minimum safe battery charge is reached. Alternatively, some devices, such as the Psion® 5™ have a secondary battery to protect memory – though this device

30   also shuts down at a minimum battery charge. While such shut-down arrangements are an effective way of protecting memory, they are extremely irritating to users, since they necessarily inhibit access to the functions of the device; premature shut down, i.e., a shut

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down before a critical battery energy level is reached, is yet more irritating and therefore undesirable.

Many such portable devices also use rechargeable batteries. However, rechargeable
5   batteries' characteristics (including the amount of energy they can store and provide) for a given charge vary (i) across their lifespan; (ii) because users often have second or replacement batteries; and (iii) because manufacturing of such batteries often does not produce batteries with consistent characteristics.

10   Combining two different types of consumer electronic device, such as a handheld computer and a cellular telephone (or a wireless LAN emitter), into a single device (a so-called "one-box" solution) presents special difficulties. First, the power conservation strategies followed by the devices are different – the cellular telephone camps, i.e., constantly cycles on and off – while the handheld computer will typically sleep or power
15   down to preserve power. Nonetheless, both devices will typically be powered by a single battery. Secondly, one device must usually be the dominant or controlling device, i.e., the 'master', and the other device the subordinate or controlled device, usually referred to as the 'slave'. Usually it is the master which will control system memory and determine when power levels have reached a critically low level, requiring a complete shut down of
20   the device so as to protect system memory. However, if the master is the handheld computer component of the device, it will not normally be able to monitor power levels while it is in a sleep state, although the cellular telephone radio component, which is camping, will continue to consume electrical power.

25   As a practical matter, the handheld computer component must normally be the master and will supply most of the principal telephone functions and features, while the functions of the cellular radio component must be limited. Thus it is the handhled computer component that would usually dial calls, decide to accept calls, display data, maintain memory, configure the telephone and control power. The slave cellular radio
30   component would usually provide signal transmission/reception as well as camping. It may have limited power management to ensure minimal transmission quality, i.e., inhibiting the cellular radio from operation if the instantaneously available power levels

are too low to transmit a signal of acceptable quality. In addition, some cellular standards such as the GSM standard allow the cellular radio to vary its transmission power depending on conditions in a given cell (e.g., distance from cellular mast), a useful facility which has the drawback of also varying power consumption by the slave device, leading

5   to uncertain energy consumption rates.

While we have described the power management problems associated with a combined handheld computer and cellular telephone, numerous master/slave arrangements raise the same or similar problems, including devices combining handheld computers with

10   wireless LAN radios such as radios operating on the IEEE 802.11 standard or the Buetooth® standard.

SUMMARY OF THE INVENTION

15   In a first aspect of the invention, there is a power management method for use in an electronic device, in which the device comprises a first section which stores volatile data and is capable of entering a sleep state and a second section which can automatically and regularly power itself up and down, and a power source powering both the first and the second sections;

20   wherein the method comprises the steps of the first section powering itself up from a sleep state automatically and a power management algorithm then operating to assess whether both the first and the second sections should be taken to a low power consumption state.

25   The invention in one implementation is a method by which a master device which enters a sleep mode during periods of non-use can monitor the power consumption of the slave device, which depends on the same battery or power source and remains in operation while the master device is in a sleep state. In principle, this implementation of the invention consists of arranging the sleep mode of the master device, so that the master

30   device will briefly and periodically partially revive and measure the remaining energy, and if the energy remaining in the power source or the battery has dropped below a certain critical level, shuts both master and slave devices down completely. The decision as to

when to shut down can be arranged in either of three ways – (i) the device can have a preset threshold based on a calculation of maximum likely power consumption by the slave device before the next revival of the master device, or (ii) the master device can engage in a dynamic calculation of power consumption rates. When this calculation

5   determines that remaining power will drop below the level necessary to protect data before the next scheduled revival of the master, the devices are shut down, or (iii) the master can simply reset its next revival time so as to allow it to shut down the joint devices when the power remaining in power source or battery is at a minimum safe level to protect the data stored in the device. In addition, the master device may in certain

10   arrangement be capable of resetting certain device parameters of the slave device to lower its power consumption, by for example elongating the off periods in the camp mode of a cellular telephone.

BRIEF DESCRIPTION OF THE DRAWINGS

15
Figure 1 is a schematic of a master/slave device containing a computer linked to a GSM modular radio.

Figure 2 is a flowchart of the method of operation of the power management arrangement, with a broken line delineating the power management/sleep steps of the

20   flowchart.

Figure 3 is a flowchart illustrating the area delineated by the broken line in Figure 2 when a dynamic power management method is in use.

DETAILED DESCRIPTION

25
The invention is described with respect to a device at present under development by Psion PLC of Great Britain which comprises a GSM or UMTS cellular radio combined in a single device with a handheld computer, collectively powered by a single rechargeable battery, which is potentially replaceable by the user. The handheld

30   computer's principle function is to store and display e-mails and other forms of data received over the GSM/UMTS network. It should be apparent that variations on this arrangement are possible, including but not limited to replacing the GSM/UMTS cellular radio with another type of cellular telephone radio or a wireless local area network radio

(wireless LAN) or other slave device which is either consistently on or camps while an associated master device sleeps.

In one implementation as illustrated in **Figure 1**, the GSM radio is combined with a
5   handheld computer which operates using a microprocessor developed by Psion and known as Halla which is based on the ARM920T™ processor and which is based on a 16/32 bit embedded reduced instruction set (RISC) cached processor macro-cell core developed by ARM Holdings PLC of the United Kingdom as part of a family of processors referred to as the ARM9™ Thumb® series. Development kits, including
10   development boards for this ARM920T™ are available from ARM and further detailed information is available from the ARM PLC website http://www.arm.com. Halla incorporates a power measurement function which measures the energy gain of rechargeable batteries during charging and can measure subsequent power consumption providing an accurate measure of remaining battery charge. Alternately, microprocessors
15   such as the bq2945 Gas Gauge IC manufactured by Benchmarq Microelectronics Inc., of the United States are available which measure the available charge in NiCd, NiMH, and Li-Ion batteries, and which can be integrated into a battery pack, or into the device. These devices typically reset after the battery is fully recharged, to a predetermined presumed energy capacity for the battery and measure power consumption from that
20   point.

In the implementation as illustrated in **Figure 1**, the device has four principle components, a battery: a GSM radio module, a computer, and a real time clock ("RTC") which is always ON. The operating system of the computer is provided with a standard
25   sleep function, which initiates a sleep routine, if after a predetermined time, no user inputs have been detected by the computer. As illustrated by the flowchart in **Figure 2**, the basic sleep routine consists of addressing the system gas gauge to determine the remaining battery energy ("E_R") at the time the sleep routine is initiated, and writing a record to the system's RAM of that measured energy level. If the energy level is below a
30   preset critical energy ("E_C") the entire device is shut down (or placed in a safety mode) including both the master and the slave devices. If the remaining battery energy is more than the preset critical energy, the device writes an end time for the sleep period to the

RTC, and places the master component, i.e., the computer in a sleep mode. At the end of the sleep period set by the clock, it revives the computer by causing an interrupt to be sent to the processor, invoking an interrupt handler to run a script carrying out a short routine, which does not include powering user interfaces or displays. In this first aspect of the invention the routine consists of measuring the remaining battery energy, and if it is below the preset critical energy, shutting down the device, and if it is greater than the preset critical energy writing an end time for a new sleep period to the RTC and placing the master component, i.e., the computer, into a new sleep period.

The system will perform a measurement of the remaining power in the battery and only place the device in a sleep mode if that remaining energy is higher than a preset minimum for allowing the master component to sleep.

The sleep periods ("T_s") are calculated by dividing the available energy ("E_A"), which is equal to the remaining energy minus the critical energy ($E_R - E_C$) by a pre-set value for energy consumption by the cellular component per unit time while camping ("P_C"), and dividing the time value thus obtained by a preset number ("N") which is greater than 1, i.e.,

$$T_S = (E_R - E_C)/(P_C \times N)$$

N is described as a heuristic factor and will usually have a value of 1.5 to 2. N may have a variable value greater than 1, which is calculated by comparing the energy consumption rate during the previous sleep cycle and comparing it with an average calculated for either all previous sleep cycles of a finite number of previous sleep cycles, and if the energy consumption during the last sleep cycle exceeds one standard deviation, increasing the preset initial value of N by 1 (or another selected value).

P_C is calculated by determining the energy consumption rate by the slave during the previous sleep cycle.
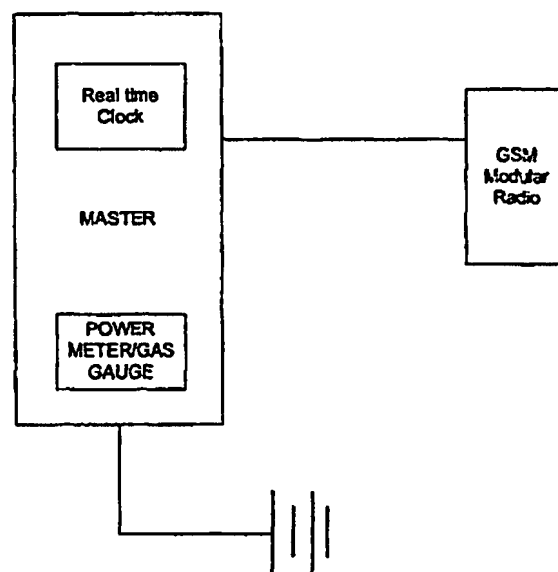
CLAIMS

1.   A power management method for use in an electronic device, in which the device comprises a first section which stores volatile data and is capable of entering a low power

5   consumption state and a second section which can automatically and regularly power itself up and down, and a power source powering both the first and the second sections;

        wherein the method comprises the steps of the first section powering itself up from a low power consumption state automatically and a power management algorithm then operating to assess whether both the first and the second sections should be taken

10   to a low power consumption state.

2.   The method of Claim 1 in which the power management algorithm causes both the first and the second section to be taken to a low power consumption state on the basis of an inference of likely future power consumption based on pre-defined figures.

15

3.   The method of Claim 1 in which the power management algorithm causes both the first and the second section to be taken to a low power consumption state on the basis of a calculation of actual power useage.

20   4.   The method of Claim 1 in which the power management algorithm is operable to cause the elapsed time before the first section is automatically revived from sleep to be varied.

5.   The method of Claim 1 in which the first section can vary one or more

25   parameters relating to the power consumption of the second section in dependence on an output from the power management algorithm.

6.   The method of Claim 1 in which the first section comprises a computing device and the second section comprises a communications device.

30

7.   The method of Claim 1 in which the second section automatically and regularly powers itself up and down as part of a camping process.

8.   An electronic device programmed to perform any of the above methods defined
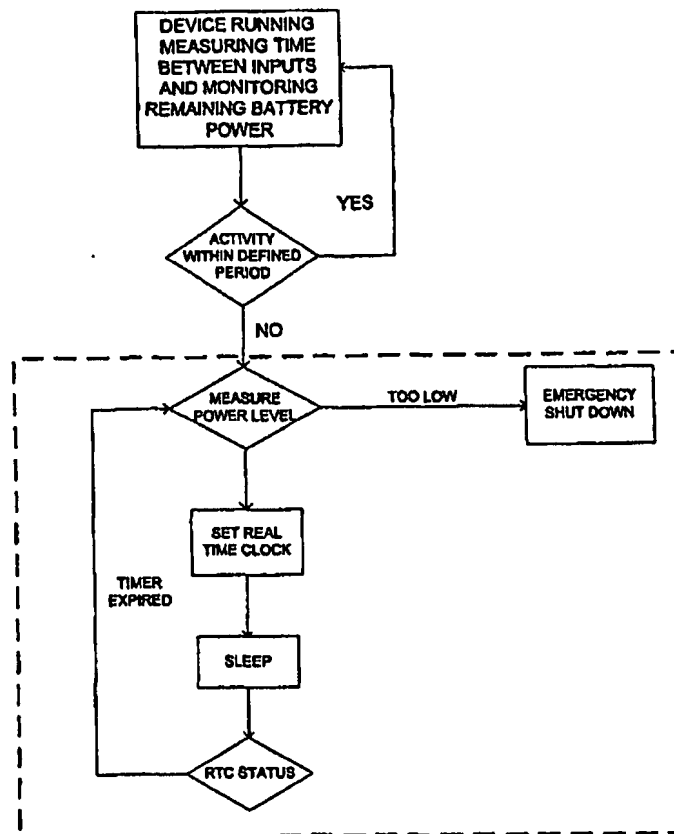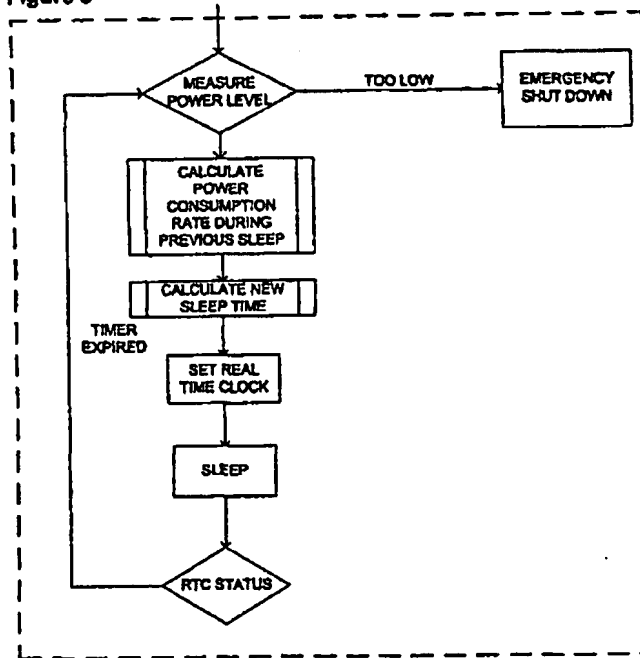in Claims 1 – 7.

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Figure 1

Figure 2

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Figure 3

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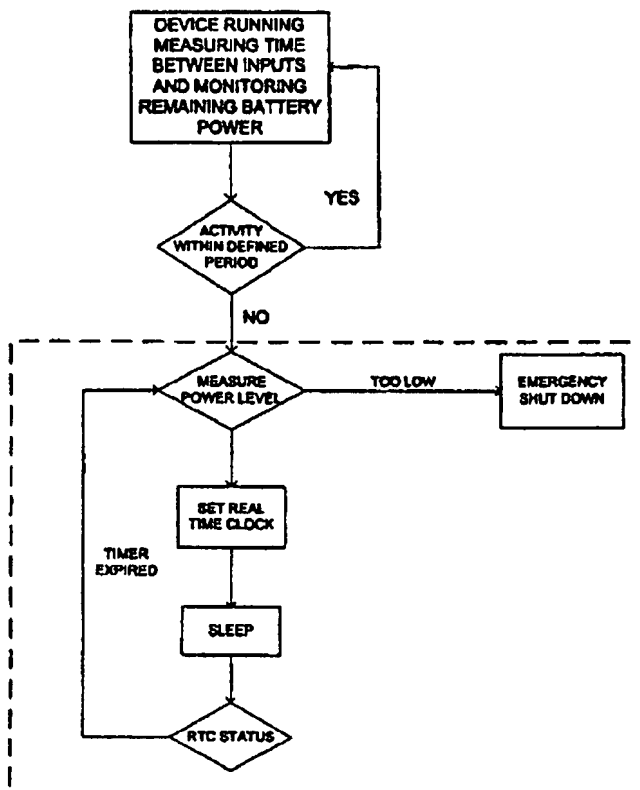
(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: KHAN, Abul, Basher

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INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   G06F1/32

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B. FIELDS SEARCHED

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 845 142 A (HAYASAKA HISASHI) 1 December 1998 (1998-12-01) abstract column 1, line 42 -column 2, line 38	1
A	WO 99 35557 A (MICROSOFT CORP) 15 July 1999 (1999-07-15) abstract page 1, line 1 -page 4, line 21	1

☐ Further documents are listed in the continuation of box C. ☒ Patent family members are listed in annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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A MAC Algorithm for Energy-limited Ad-hoc Networks

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Abstract

Energy efficiency is an important issue in ad-hoc wireless networks since the battery power of terminals is limited. In this paper, we propose energy efficient MAC algorithm based on reservation and scheduling for ad-hoc wireless networks. The performance of our proposed MAC scheme is evaluated in view of the number of delayed slots, the channel utilization, and the energy efficiency.

1. Introduction

An ad-hoc wireless network consists of wireless mobile terminals forming a temporary network without any deployed infrastructure or centralized administration. Each mobile terminal that communicates with the others has a autonomous algorithm. Ad-hoc networks are evolved largely from the DA-RPA packet-radio network program [1]. Recently, the ad-hoc networks are expected to play an important role in commercial and military environments. Especially, the ad-hoc networks are very useful in situations where it is very difficult to provide the infrastructures and it is required to be rapidly deployed because of earthquake environment, robot cooperation for jobs in inland places, and military operations etc. The architecture of ad-hoc wireless networks can be either hierarchical or flat. In hierarchical networks, the network elements are partitioned into several clusters that have a clusterhead which is selected to manage all the other nodes within the cluster. In flat networks, all nodes are in the equal rank [2], [5].

A general constraint we face is the short lifetime of mobile terminal batteries. Hence, energy efficient protocols are needed to reduce the effect of this constraint in many ad-hoc wireless networks. The terminals usually operate with a limited battery energy in ad-hoc wireless networks. So, a system design considering power saving is important [3]. It has recently been recognized that media access control (MAC) protocols could significantly reduce the power consumption of mobile terminals in ad-hoc wireless networks. In general, the radio module consumes more power in the tx. mode than in the rx. mode. In the idle mode, least power is consumed by the radio module. If mobile terminal A transmits data to mobile terminal B, the neighbor mobile terminals don't need to listen the data from mobile terminal A to prevent unnecessary rx. power consumption. Collision needs to be removed as soon as possible since it causes retransmissions that result in unnecessary power consumption. The existing works on ad-hoc wireless networks are almost biased toward routing protocols but there is a need for energy efficient MAC protocols.

The rest of the paper is organized as follows. The next section presents the proposed energy efficienct MAC scheme in ad-hoc wireless networks. Section III provides the performance analysis and section IV concludes this paper.

2. The proposed energy efficient MAC

In this paper, we propose a MAC algorithm considering limited battery energy in single hop ad-hoc wireless networks based on the CDMA/TDMA. The proposed MAC algorithm is based on reservation and scheduling method that informs each terminal when to wake up from idle mode or when to go to idle mode for its power saving.

There are two sorts of mobile terminals with full duplex operation in the proposed MAC scheme, i.e. pseudo base station (PBS) and normal mobile terminals. The PBS among mobile terminals is elected according to battery power level. Every terminal can be qualified to a PBS. The PBS collects the requests of mobile terminals and allocates the CDMA code and the TDMA slots considering a priority and battery level of terminals. Transmission procedure in the proposed MAC is performed based on frames and the PBS controls the frames. The frames are handled at multiple phases using the CDMA codes and TDMA slots. The protocol in terms of multiple phases has been researched [4], [6]. The new features of the proposed MAC scheme are support for single hop ad-hoc wireless networks, the easy combination with the hierarchical ad-hoc networks, consideration for limited battery energy, and efficient direct communication.

The frame consists of four phases that are the Frame Synchronization phase, the Request/Update/New Mobile phase, the Scheduling phase, and the DataTxRx phase. Terminals that want to transmit packets should send requests to the PBS in the Request/Update/New Mobile phase and listens scheduling message in the Scheduling phase. Then, terminals transmit packets using scheduled TDMA slots and CDMA codes. Also, terminals that don't have any packets to receive and to transmit stay in idle mode in the Request/Update/New Mobile phase and stay in the rx. mode in Scheduling phase. We show the frame structure in Figure 1. In each phase of a frame, the PBS and normal terminals operate as following.
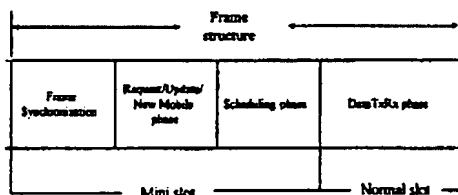

Figure 1. Frame structure

Frame synchronization phase

At the start of each frame, the PBS transmits the frame synchronization message to the terminals. This message contains synchronization information and the order information for packet transmission. Hence, there is no contention in Request/Update/New Mobile phase. Hence, power saving could be obtained. The PBS and other mobiles are in the wake-up mode.

Request/Update/New Mobile phase

The Request/Update/New Mobile phase is composed of the requests and power level update from the terminals. The PBS consumes rx. power during this phase and the mobile terminals that have traffics to send consume rx. power during one minislot. The mobile terminals that don't have traffics to transmit are in the idle mode. A new mobile terminal registers the PBS at last minislot time of this phase.

Scheduling phase

Every terminal operates with full duplex mode. Therefore, it can't receive or transmit packets from or to two terminals at the same time. The scheduling is based on a simple priority round robin. The PBS broadcasts a scheduling message that contains the TDMA slots and CDMA code permission for the subsequent phase. The PBS consumes tx. power during this phase and the others consume rx. power during one mini-slot and are in the idle mode during the others.

DataTxRx phase

The mobile terminals including the PBS communicate with each other by using allocated TDMA slots and CDMA codes avoiding collisions. The terminals that don't have traffics to send or to receive consume idle power. Terminals transmit and receive traffics directly without the PBS. Hence, we can acquire power saving effect.

We show the proposed MAC algorithm in Figure 2. A terminal can move to the other group and join it.
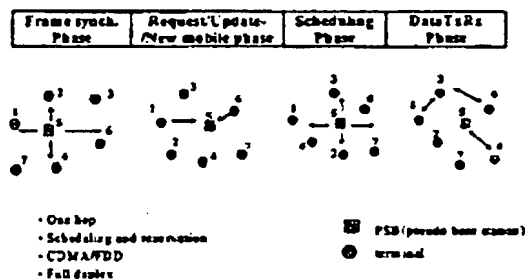

Figure 2. The proposed MAC Algorithm

3. Simulation results and Discussion

Simulations are performed to analyze single hop ad-hoc wireless networks adopting our proposed MAC algorithm. The terminals are classified into high power (HP) or low power (LP) terminals according to battery energy level. The proposed MAC scheme is designed to use the mini-slots for the channel request and scheduling since they require the lower battery energy than slots in the DataTxRx phase. If the battery energy of a LP terminal is particularly lower than the threshold, it is classified into LP terminal. We give the priority for scheduling to the LP terminal.

3.1 Simulation parameters

There are N terminals including PBS terminal. The Frame Synchronization phase has M_1 mini-slots and the Request/Update/New Mobile phase M_2 mini-slots and Scheduling phase M_3 mini-slots and DataTxRx phase M_4 slots. In the DataTxRx phase, there are Q codes. The α mini-slots are equal to one normal slot in the DataTxRx phase. We define frame period such that

$$P_{frame} = \frac{M_1 + M_2 + M_3}{\alpha} + M_4 \qquad (1)$$

We assume that there are no packet losses by wireless links. Each terminal generates the data traffics that have ON or OFF traffic model. During ON period, arrival packet of the terminal has Poisson distribution with rate λ. The probability that a terminal i transmits n slots to a terminal j is given by

$$P(x_{i,j} = n) = e^{-\lambda} \frac{\lambda^n}{n!} \cdot \frac{1}{N-1} \qquad i = 1,2,3,\cdots,N \quad i \neq j \qquad (2)$$

Let y_i be number of slots to be destined for a terminal i. The PBS is requested to allocate y_i slots. Then, y_i is can be expressed by

$$y_i = \sum_{\substack{j=1 \\ j \neq i}}^{N} x_{i,j} \qquad (3)$$

The delay happens in two cases. First, the delay occurs because a terminal y_i can get the maximum M_4 slots. Second, when total slots requested is more than system capacity that is the product of M_4 by Q. The delayed slots are scheduled with high priority. The parameters used for simulations are listed in Table 1.

Table 1. Simulation parameters

Name	Value	Description
λ	10	Arrival rate in Poisson distribution
α	3	Mini-slot ratio
M1	10	No. of slots in frame synchronization phase
M2	N+1	No. of slots in request/update-/new mobile phase
M3	N	No. of slots in scheduling phase
M4	30	No. of slots in DataTxRx phase
Q	5	No. of codes
P_{tx}	0.1	Energy consumption in the tx. mode
P_{rx}	0.5	Energy consumption in the rx. mode
P_{idle}	0.01	Energy consumption in the idle mode

3.2 Simulation results

In our simulation, the 30% of all terminals are LP terminals. We define the energy efficiency as the ratio of total energy consumed to total slots used in the DataTxRx phase. The channel utilization is defined as the ratio of total slots used in the DataTxRx phase to the total system capacity. The total system capacity is the product of total slots P_{frame} by total code Q in a frame. The performance of our MAC scheme is studied through the number of delayed slots, the channel utilization, and the energy efficiency. The simulation ends when a battery energy level of some terminal equals to zero.

The number of delayed slots for LP and HP terminals show that LP terminals have lower values. Since LP terminals have priority when allocating slots and code, the gap between LP terminals and HP terminals is larger as number of terminals is increasing.

Figure 4 provides channel utilization curve that shows no difference when number of terminals is small. The larger load to system causes the degradation of the channel utilization since the channel resources are limited.

Figure 5 shows the energy efficiency curve that LP terminals consume lower battery energy than HP terminals. For HP terminals, the energy efficiency is lower as number of terminals is increasing because the overhead for the request and the scheduling in frames are smaller relatively. However, we see that the energy efficiency for HP terminals is higher in heavily-loaded case. It is due to the additive energy consumption caused by the retransmission. LP terminals have the priority compared with HP terminals. So, It makes LP terminals communicate with small battery energy consumption.
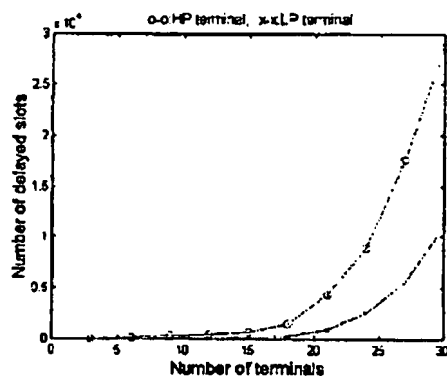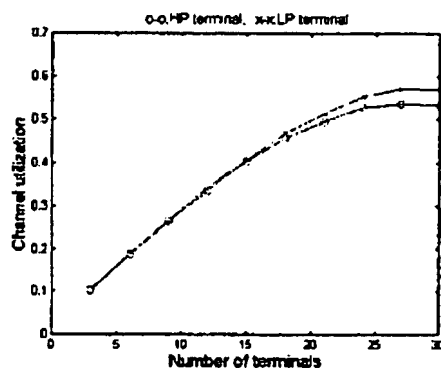
Figure 3. Number of delayed slots

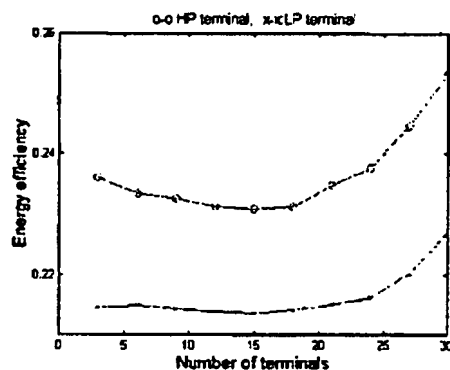
Figure 4. Channel utilization

Figure 5. Energy efficiency

4.Conclusions

In this paper, we propose the energy efficient MAC algorithm based on scheduling and reservation for single hop ad-hoc wireless networks. When the data traffics are generated heavily, the proposed MAC scheme prevents terminals from collisions and retransmissions that cause additive battery energy consumption and also informs terminals of when to transmit and when to receive packets. Our reservation-based approach provides reduced battery energy consumption over wireless links. We evaluate the performance analysis of the MAC scheme with respect to the number of delayed slots, the channel utilization, and the energy efficiency versus number of mobile terminals, i.e. the traffic load. We show that LP terminals can take communications with the efficient energy consumption and experience smaller delay than HP terminals.

For further study, the proposed MAC scheme can be easily combined with hierarchical routing schemes, for example clusterhead gateway switch routing (CGSR) because the PBS can control a group of ad-hoc mobile terminals like a clusterhead in the CGSR. The operation protocols among PBSs need to be developed.

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